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LEVEL II 12

FIELD STUDY DETERMINATION OF VENTILATORY REQUIREMENTS OF MEN RAPIDLY EVACUATING A SPACE LAUNCH COMPLEX

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USAF SCHOOL OF AEROSPACE MEDICINE
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NOTICES

This final report was submitted by personnel of the Crew Protection Branch, Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 7930-14-06.

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The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 80-33.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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20 ABSTRACT (Continue on reverse side if necessary and identify by block number)

Physiological variables, including heart rate and minute ventilation, were monitored for 3 men and 1 woman during field trials simulating the emergency evacuation of Space Launch Complexes (SLC) 4E and 4W at Vandenberg AFB in January 1980. Rapid evacuation from the highest work level of SLC-4E to a designated point of safety (tunnel), unencumbered by the wearing of a respiratory protection device, could be accomplished in about 3 min. Monitored heart rates for 3 men, calculated at 30-sec intervals, averaged 145 bpm; peak heart rates

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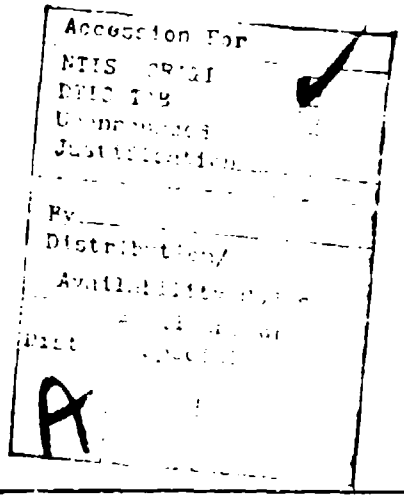
20. ABSTRACT (continued)

averaging 166 bpm occurred during the last min of the exercise. Ventilatory requirements for this rate of work, estimated to represent approximately 65% of the men's aerobic capacity, were estimated to average approximately 51 liters/min. Subsequent trials repeating the same rapid evacuation while wearing the currently approved Robertshaw Air Capsule were achieved with considerable difficulty, producing situations that could seriously compromise the wearer's safety. Most obvious hazards imposed by the air capsule included (1) almost total obstruction (fogging) of forward and downward vision, (2) the early onset and progressive severity of dizziness, allegedly the result of hypoxia, (3) the total collapsing of the air capsule around the head and face with each inspiration, and (4) the absence of an anti-suffocation device which would allow entry of outside air into the air capsule when the air reservoir becomes exhausted. However, the user is indeed cautioned to walk when wearing the Robertshaw Air Capsule, and there were no major complaints during evacuation from the SLC when it was used in this manner. Time required to accomplish a walking evacuation averaged 4 min, 19 sec; total air supply to the air capsule averaged about 4 min, 54 sec for the 5 units tested. It should be noted that although present regulations and directives state that workers should walk, not hurry down the SLC tower stairway and into the tunnel, such a disciplined evacuation in an emergency situation may be merely academic.

It was concluded that a reasonably fit adult male rapidly evacuating the SLC works at a load approximating 65% of his aerobic capacity. Associated with this level of work is a ventilatory requirement of about 51 liters/min with corresponding peak inspiratory flow rates predicted to average about 180 liters/min. Under these conditions excessive rebreathing of expired air with the concomitant onset of hypoxia was clearly evident when wearing the Robertshaw Air Capsule which delivers air at a rate of 25 liters/min. The Robertshaw Air Capsule is deemed to be unsuitable as a respiratory protection device during rapid evacuation of the SLC; its limited air supply (about 5 min) renders it a marginal device for a walking evacuation which requires about 4 min, 19 sec. The degree of protection from airborne contaminants provided by the Robertshaw Air Capsule under work stress conditions simulating both (a) rapid and (b) walking evacuation awaits laboratory testing.



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INTRODUCTION

The USAF School of Aerospace Medicine, Crew Technology Division (USAFSAM/VN), was requested by USAF Headquarters Space Division, Space and Missiles Systems Organization (SAMSO/SGX) to test a respiratory protection device which has been recently added to the USAF inventory at Vandenberg AFB. This 5-min escape device, the Robertshaw Air Capsule, was procured to meet the need for protecting a worker evacuating a Space Launch Complex during an emergency typified by a rocket fuel/chemical leak into the working environment.[1]

Robertshaw Air Capsule

The Robertshaw Air Capsule, P/N 900-002-768-12, is a universal-fit escape device manufactured by Robertshaw Controls Company and has been issued National Institute for Occupational Safety and Health (NIOSH) approval number TC-13F-28 for a 5-min self-contained breathing apparatus. It consists of an air reservoir which is connected to an inflatable polyvinyl chloride (alternate hood materials are Kapton and polyurethane) hood which envelopes the head and is secured by an elastic neck seal. The reservoir coil is made of 304 stainless-steel tubing, pressurized with breathing air to 5000 psig and stored in a small packet attached to the hood, and rests on the back just below neck level. When actuated, air flows through a pressure regulator and a supply hose into the plastic hood at a rate of approximately 25 liters/min for about 5 min. (Data describing the air space in the hood when worn by an average man are not available at this time.) When in use, air flow from the reservoir is complemented by expired air which simply inflates the capsule until a given positive pressure forces excess air to the outside through an expiration valve.

Space Launch Complex

The space launch complex (SLC) consists of a tower rising more than 200 ft (61 m) above a launching pad which is about 12 stories above ground level; SLC-4E and SLC-4W are illustrated in Figures 1 and 2, respectively. Although serviced by elevators, emergency egress from the tower is by open stairway, adequately designed for safety but open to the external (weather) environment. After descending the tower and upon arrival on the pad, the worker must continue to leave the area by one of several routes partly dependent upon wind

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[1] Robertshaw Air Capsules are provided for use on Space Launch Complexes 4-East (SLC-4E) and 4-West (SLC-4W) at Vandenberg AFB.

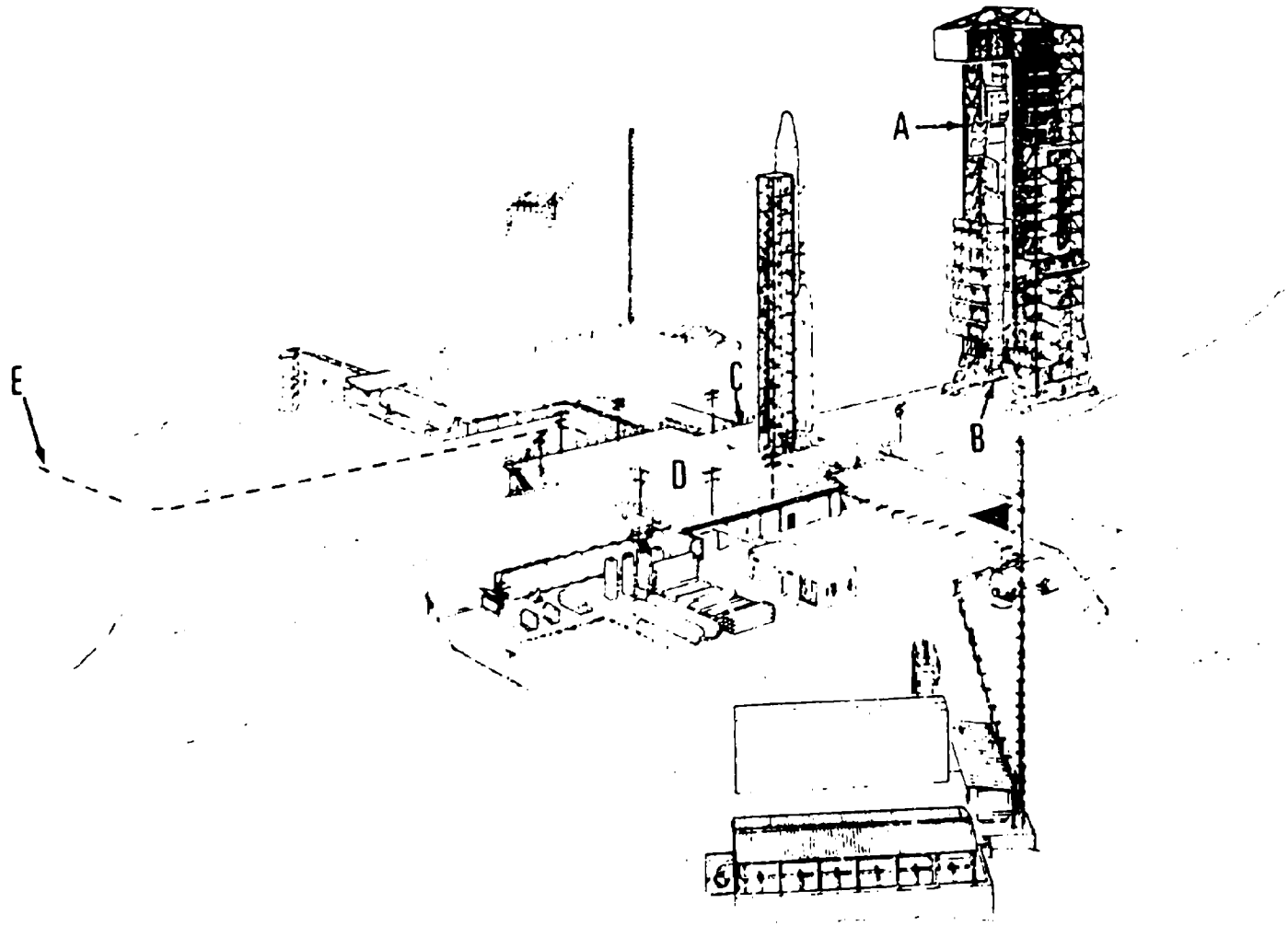

Figure 1. Illustration of Space Launch Complex 4-East annotated to indicate tower level 16 (A), stairway from tower level 1 to pad (B), stairway from pad to ground level (C), block house above safety tunnel (D), and evacuation route leading to road intersection (E).

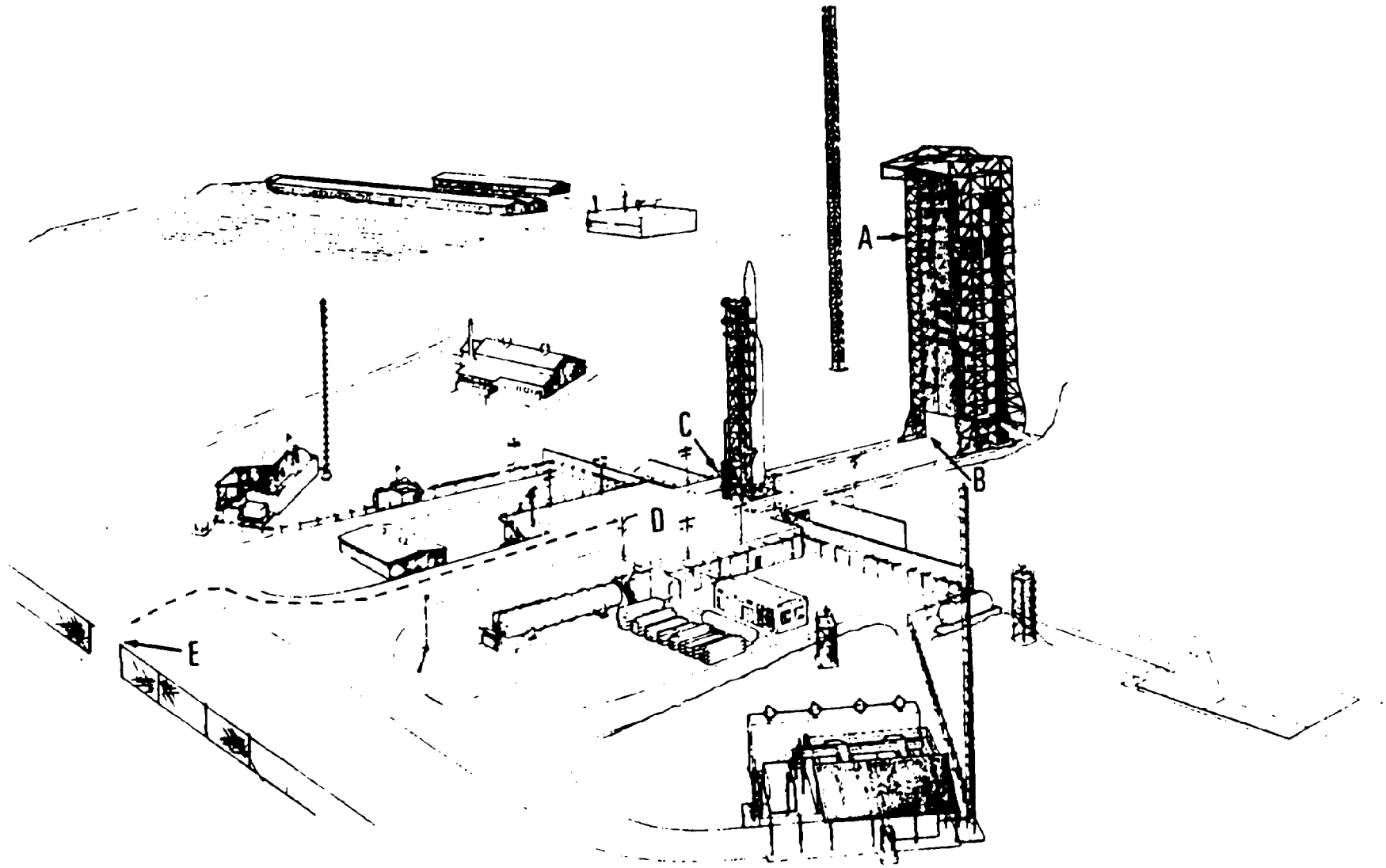

Figure 2. Illustration of Space Launch Complex 4-West annotated to indicate tower level 149 (A), stairway from tower level 1 to pad (B), stairway from pad to ground level (C), block house above safety tunnel (D), and evacuation route leading to perimeter fence (E).

direction, but the primary route of escape for most weather conditions is one leading to an underground tunnel considered safe from atmospheric contaminants.[2] Tunnel entry is made by descending a flight of stairs from the launch pad to actual ground level, then entering a building and descending a stairway leading to the tunnel. Alternate routes are over land in all directions from the SLC. A description of the corresponding distances navigated in the evacuation exercises is given in Appendix A.

Primary Objectives

Primary Objectives of this effort included the following:

a. To identify the physical characteristics of the worker population attending the SLC.

b. To determine the time required to evacuate the tower and reach a point of safety.

c. To estimate the physical stresses imposed on workers during SLC evacuation, thus to provide an estimate of the ventilatory requirements to be placed on a respiratory protective device.

d. To evaluate the current Robertshaw Air Capsule under actual SLC evacuation exercises.

e. To develop a work stress scenario to be used in laboratory testing of the degree of protection afforded by the current Robertshaw Air Capsule when used in a manner simulating SLC evacuation.

METHODS AND PROCEDURES

The protocol for monitoring the field trial was dictated by the directive to be followed in emergency SLC evacuation. In general, the workers are to leave the tower work area by exiting to the nearest outside stairwell. They are instructed to pick up a Robertshaw Air Capsule from the supply provided at each work level, properly affix the capsule over the head, and then walk downstairs and continue on to the determined point of safety. The worst-case experiment simulated evacuation from level 16 of SLC-4E, the highest (160 ft) (48.8 m) level where workers may be found when the Titan rocket is being prepared for launching. Evacuation from level 11 (110 ft) (33.5 m) was also included in the testing protocol because it was the site most frequented by SLC workers. Corresponding levels for SLC-4W were 149 (149 ft) (45.4 m) and 129 (129 ft) (39.3 m), respectively.

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[2]The tunnel is serviced by an air-conditioning system which keeps the tunnel under a slight positive pressure, i.e., any movement of air (contaminants) should be outward from the tunnel.

Physical characteristics of the 3 military and 1 civilian personnel who were monitored during SLC evacuation exercises are presented in Table 1.

TABLE 1. PHYSICAL CHARACTERISTICS OF SUBJECTS

Subject No.	Sex	Age (yr)	Height (inches) (cm)	Weight (lbs) (kg) (a)	(b)
1	M	43	74 (188)	182.7 (82.9)	187.3 (84.9)
2	M	32	70 (178)	182.7 (82.9)	187.8 (85.2)
3	M	24	72 (183)	168.7 (76.5)	174.8 (79.3)
4	F	24	62 (157)	102.9 (46.7)	108.1 (49.0)
Mean		31	70 (176)	159.2 (72.2)	164.5 (74.6)

(a) Weighed in normal street clothes without shoes.

(b) Weighed in work clothes with shoes and hard hat.

After briefings on the use of the Robertshaw Air Capsule for evacuating the SLC area, the subjects visited SLC-4E and SLC-4W where they became thoroughly familiar with the egress plans to be followed. The subjects were then prepared with adhesive chest electrodes for medilog recording of ECG, and body weights in work clothes were recorded (see Table 1). The chest electrodes were connected to the ECG leads of the medilog recorder which was subsequently secured in the subject's pocket. The subject and an observer then ascended the tower via an elevator and, upon reaching their destination, signaled to the ground observers and then rested quietly for 5 min prior to their timed descent. The medilog recorder was activated 2 min prior to the start of the egress exercise which commenced with a signal from the ground observer. The subject then descended the stairs at his fastest safe pace while accompanied by a trained observer, usually a fellow subject. Times were recorded for the subject's arrival (1) at the bottom of the tower (pad), and (2) at a predetermined place of safety which was either at the bottom of the stairs entering the tunnel or at a ground point some distance from the tower. The medilog recorder tape was coded for experiment identification, and the instrument was then transferred to the next subject who followed the same protocol.

In addition to heart rate and evacuation time, ventilatory requirement data were obtained from 2 of the male subjects, descending from level 16 on SLC-4E and from level 149 on SLC-4W, while wearing a Scott II Air Pak (demand mode) self-contained breathing apparatus (SCBA). These same two men repeated

the rapid evacuation from the 16th level of SLC-4E, and again at a prudent walking pace from that level and from level 149 on SLC-4W, all while wearing the Robertshaw Air Capsule. Adjustments in the experimental protocol for these cases with the men wearing a respiratory protective device include the following:

SCBA Experiments

The air cylinder was carefully weighed and returned to the back pack which was carried up the tower (using the elevator) by an observer. Prior to his 5-min rest at the top, the subject was fitted with the SCBA and awaited the signal to start down. At that signal, the mask was pulled into position and tested for seal and air delivery; the subject then proceeded to descend the SLC. The mask was removed immediately upon arrival at the safety area, and the air cylinder was again carefully weighed to determine the grams (and calculated liters) of air used during the exercise.

Robertshaw Air Capsule Experiments

The Robertshaw Air Capsules for these experiments were randomly selected from those already in place in the work areas on the tower. With the signal from the ground observer, the subject followed the directions on the air capsule package by (1) opening the case, (2) pulling a cord to activate airflow into the capsule, and (3) affixing the capsule over his head; he then commenced his egress from the tower. The capsule was removed immediately upon his arrival in the tunnel, and a stop-watch recorded the remaining minutes of air supply provided by the air coil.

All experiments were performed within a 3-day period in mid-January. Weather conditions were typical for the winter season with persistent overcast, intermittent rain or drizzle, and occasional fog (see Table 2).

RESULTS

Physical Characteristics of Worker Population

Lockheed and Martin-Marietta corporations are the primary contractors for SLC operations; physical characteristics of on-site workers are summarized in Table 3.

Although no attempt was made to determine clinical characteristics, corporation records described this all-male group as being generally sedentary with resting systolic and diastolic blood pressures averaging about 126-127 mmHg and 80-86 mmHg, respectively. It should be noted that 32 of the workers weighed in excess of 200 lb (90.7 kg), and the extreme was 364 lb (165.1 kg). In contrast to the SLC worker population, the test subjects in this study were younger (mean = 31 yr), about the same height (mean = 69.5 in (177 cm)), lighter (mean = 159.2 lb (72.2 kg)), and included 1 small female (see Table 1).

Corresponding mean values for the 3 male subjects in this study were 33 yr, 72 in (183 cm), and 178 lb (80.8 kg), respectively.

TABLE 2. SUMMARY OF METEOROLOGICAL CONDITIONS EXISTING IN SLC-4E AND SLC-4W DURING THE COURSE OF EXPERIMENTAL EVACUATION EXERCISES AT VANDENBERG AFB

Date	Time	Air temperature °F (°C)	Relative humidity (%)	Comment
15 Jan	1200	61 (16.1)	89	overcast
	1400	60 (15.6)	77	overcast
	1600	57 (13.9)	97	light rain
	1800	60 (15.6)	97	light drizzle
16 Jan	1000	58 (14.4)	97	light drizzle
	1200	60 (15.6)	97	fog; 200 ft (61 m) visibility
	1400	60 (15.6)	97	overcast, some fog
	1600	60 (15.6)	97	overcast
17 Jan	1000	56 (13.3)	97	light drizzle
	1200	59 (15.0)	87	overcast

TABLE 3. PHYSICAL CHARACTERISTICS OF SLC WORKER POPULATION (MEAN ± S.E.)

Contractor	N	Age (yr)	Height (inches)	(cm)	Weight (lb)	(kg)
Lockheed	61	51.8	69.8	(177)	185.8	(84.3)
		±1.0	+0.3	(±0.8)	± 4.5	(±2.0)
Martin-Marietta	105	46.1	69.7	(177)	181.3	(82.2)
		±0.3	+0.3	(±0.8)	± ?.7	(±1.2)

Time Required to Evacuate the Space Launch Complex

Times required to evacuate the SLC at the fastest safe pace, unencumbered by any respiratory protection device, are presented in Table 4.

TABLE 4. TIMES REQUIRED TO RAPIDLY DESCEND FROM SELECTED SLC LEVELS TO PREDETERMINED POINTS OF SAFETY

Subject No.	Level	Time of arrival (min:sec)		
		Pad	Tunnel	Road/fence[a]
		SLC-4E		
1	16	1:48	2:35	
2	16	2:10	2:59	
3	16	2:20	3:07	
4	16	2:23	3:15	
Mean		2:10	2:59	
1	11	1:06		2:00
2	11	1:10		2:01
3	11	1:30		2:26
4	11	1:25		2:28
Mean		1:18		2:14
		SLC-4W		
1	149	1:32	2:13	
2	149	1:30	2:10	
3	149	2:13	3:05	
4	149	2:22	3:15	
Mean		1:54	2:41	
1	129	1:08		1:41
2	129	1:09		1:43
3	129	1:42		2:21
4	129	1:45		2:37
Mean		1:26		2:06

[a]Predetermined endpoint for evacuation exercises from level 11 of SLC-4E was on a road approximately 115 yd (105 m) from launch pad; for level 129 of SLC-4W the egress endpoint was a perimeter fence (wirecutter location) approximately 190 yd (174 m) from the launch pad (see Figures 1 and 2).

From Table 4 it may be seen that the 4 subjects in this study, moving as rapidly as possible and unencumbered by any respiratory protection device, were able to leave the highest probable work levels on SLC-4E and SLC-4W and arrive in the corresponding safety tunnels in an average time of 2:59 and 2:41 (min:sec), respectively. Average times from pads to tunnels were 0:49 sec and 0:47 sec for SLC-4E and SLC-4W, respectively. As a comparison, 2 of the male subjects repeated these evacuation exercises while wearing a SCBA and again while wearing a Robertshaw Air Capsule; these results are presented in Table 5.

TABLE 5. TIME REQUIRED TO RAPIDLY DESCEND FROM SELECTED SLC LEVELS TO CORRESPONDING SAFETY TUNNELS WHILE WEARING A RESPIRATORY PROTECTION DEVICE

Subj. No.	Level	Respiratory protection device	Time required (min:sec)				
			Don air capsule	Arrival at Pad	Arrival at Tunnel	Actual walking time Free	Actual walking time RPD[a]
			SLC-4E				
1	16	SCBA	NA	1:59	2:53	2:35	2:53
2	16	SCBA	NA	2:12	3:02	2:59	3:02
1	16	Robertshaw	0:40	3:05	3:41	2:35	3:01
2	16	Robertshaw	0:13	2:13	3:04	2:59	2:51
			SLC-4W				
1	149	SCBA	NA	1:34	2:24	2:13	2:24
2	149	SCBA	NA	1:31	2:13	2:10	2:13

[a]While wearing the respiratory protection device.

Although the SCBA is not used as a respiratory protection device for evacuating SLC-4E and SLC-4W, its inclusion in this study was simply for providing a means of determining the total ventilatory requirements of the subjects following the approved SLC evacuation exercises. However, in spite of its bulk and weight (about 32.5 lb) (14.7 kg), the men were able to descend the tower and arrive in the safety tunnel in about the same time as was required to do so without a respiratory protection device. Although the Robertshaw Air Capsule presented less of a physical burden, rapid descent from SLC-4E was achieved only with considerable difficulty and it was decided to cancel plans to repeat its use under these conditions on SLC-4W. However, it should be noted that the directive for emergency SLC evacuation specifies that the worker will walk, not run down the tower stairs and into the tunnel. Thus, data were collected from these same 2 male subjects wearing a Robertshaw Air Capsule while performing a walking evacuation from these same tower levels and are presented in Table 6.

TABLE 6. TIME REQUIRED TO DON THE ROBERTSHAW AIR CAPSULE AND WALK FROM HIGHEST SLC WORK LEVELS TO CORRESPONDING SAFETY TUNNELS

Subj. No.	Level	Time required (min:sec)			
		Don air capsule	Arrival at Pad	Arrival at Tunnel	Actual walking time
		SLC-4E			
1	16	0:31	3:20	4:55	4:24
2	16	0:26	3:16	4:34	4:08
		SLC-4W			
1	149	0:29	3:10	4:31	4:02
2	149	0:24	2:53	4:24	4:00

In summary, the time required to open the packet and don the Robertshaw Air Capsule averaged about 27 sec. With capsule donning time included, the subjects were able to rapidly descend from level 16 of SLC-4E in an average of 3 min 23 sec; a walking descent required 4 min 45 sec.

Physical Stresses Imposed on Workers During SLC Evacuation

The solicitation of Lockheed and/or Martin-Marietta workers as volunteer subjects for this study was not authorized. Thus, data collected from the younger, probably more fit USAF subjects must be considered accordingly. The two objective physiological parameters studied for the purpose of estimating the workload imposed during SLC evacuation were (1) minute ventilation, and (2) heart rate. The ventilatory requirements, calculated from the weight loss of the SCBA cylinder during the evacuation exercises, are presented in Table 7.

The ventilatory requirements for these men, who were essentially the same weight, were very similar, averaging 64.6 liters/min and 68.8 liters/min, STPD, for subjects 1 and 2, respectively.

Subject heart rates were recorded continuously during all rapid evacuation exercises and are presented in Table 8.

Heart rates monitored for all subjects during the rapid evacuation from level 16 of SLC-4E averaged 143, 150, and 167 for minutes 1, 2, and 3, respectively. Ventilatory values (see Table 7) combined with heart rate data for subjects 1 and 2 further define the evacuation exercise as being moderately hard to hard physical work. The female subject performed the test exercise without the air capsule with slightly less speed (Table 4), but with about the same heart rate response (Table 8) as that observed for her male counterparts.

TABLE 7. CALCULATED VENTILATORY REQUIREMENTS OF TWO MALE SUBJECTS RAPIDLY DESCENDING FROM A SELECTED SLC LEVEL TO ITS CORRESPONDING SAFETY TUNNEL

Subject No.	Subject Weight[a] (lb) (kg)	Level	Time of arrival in tunnel (min:sec)	Ventilatory requirement: Total liters, STPD[b]	Ventilatory requirement: Liters/min, STPD[b]
			SLC-4E		
1	219.4 (99.5)	16	2:53	206	71.4
2	220.3 (99.9)	16	3:02	202	66.6
			SLC-4W		
1	219.4 (99.5)	149	2:34	148	57.7
2	220.3 (99.9)	149	2:18	163	70.9

[a]Subject weight includes the 32.5 lb (14.7 kg) SCBA.

[b]Correcting according to gas laws for standard temperature (0°C), standard pressure (760 mmHg), and dry.

TABLE 8. HEART RATES RECORDED DURING RAPID EVACUATION WITHOUT A RESPIRATORY PROTECTION DEVICE FROM SELECTED SLC LEVELS TO PREDETERMINED POINTS OF SAFETY

Subject No.	Level	Heart rate (bpm)									
		Time during evacuation (min)									
		-1	0	½	1	½	2	½	3	½	4
					SLC-4E						
1	16	62	57	120	143	146	149	150			
2	16	74	75	113	113	120	146	161	173		
3	16	98	86	144	158	154	150	158	176		
4	16	119	103	140	157	167	155	161	152		
Mean		88	80	129	143	147	150	158	167		
±SE		±13	±10	± 8	±11	±10	± 2	± 3	± 8		
1	11	68	75	135	150	147	156				
2	11	105	102	160	184	180	176				
3	11	-	-	-	-	-	-	-			
4	11	115	101	145	165	173	180	185			
Mean		96	93	147	166	167	171	185			
±SE		±14	± 9	± 7	±10	±10	± 7	± 0			
					SLC-4W						
1	149	57	60	102	139	143	150	152			
2	149	98	99	155	170	177	173	180			
3	149	94	89	125	137	139	138	128	150	155	
4	149	109	90	116	126	118	128	125	137	143	
Mean		90	85	125	143	144	147	146	143	149	
±SE		±11	± 9	±11	± 9	±12	±10	±13	± 7	± 6	
1	129	60	79	140	143	150	152				
2	129	111	117	165	180	186	177				
3	129	101	94	119	135	134	150	180			
4	129	83	85	122	120	134	153	158			
Mean		89	94	137	145	154	161	169			
±SE		±11	± 8	±11	±13	±13	± 6	±11			

Space Launch Complex Evacuation While Wearing the Robertshaw Air Capsule

Times and heart rate data collected from subjects 1 and 2 during rapid evacuation from SLC-4E, with and without protective breathing devices, are presented in Table 9.

Subject 2 evacuated the tower at a nearly identical pace under all three experimental conditions, namely (1) without a breathing device, (2) wearing a 32.5 lb (14.7 kg) SCBA, and (3) wearing the 4.65 lb (2.1 kg) Robertshaw Air Capsule. The additional stress imposed by the weight of the SCBA was evident in the slightly higher heart rates observed during work as shown in Figure 3.

TABLE 9. HEART RATE RESPONSES OF TWO MEN DURING RAPID EVACUATION OF LEVEL 16 SLC-4E WITH AND WITHOUT USE OF A RESPIRATORY PROTECTION DEVICE

Condition	Total time (min:sec)		Heart rate (bpm) Time during evacuation (min)							
	Evacuation	Air supply	-1	0	½	1	½	2	½	3
			Subject 1							
Free	2:35	NA	62	57	120	143	146	149	150	
SCBA[a]	2:53	NA	65	75	139	146	150	150	150	154
Robertshaw Air Capsule[b]	3:01	5:05	60	64	79	128	114	122	---	150
			Subject 2							
Free	2:59	NA	74	75	113	113	120	146	161	173
SCBA[a]	3:02	NA	110	113	123	120	131	165	173	160
Robertshaw Air Capsule[b]	2:51	--	94	108	120	169	171	170	180	180

[a]Total weight of SCBA: 32.5 lb (14.7 kg)

[b]Total weight of Robertshaw Air Capsule: 4.65 lb (2.1 kg)

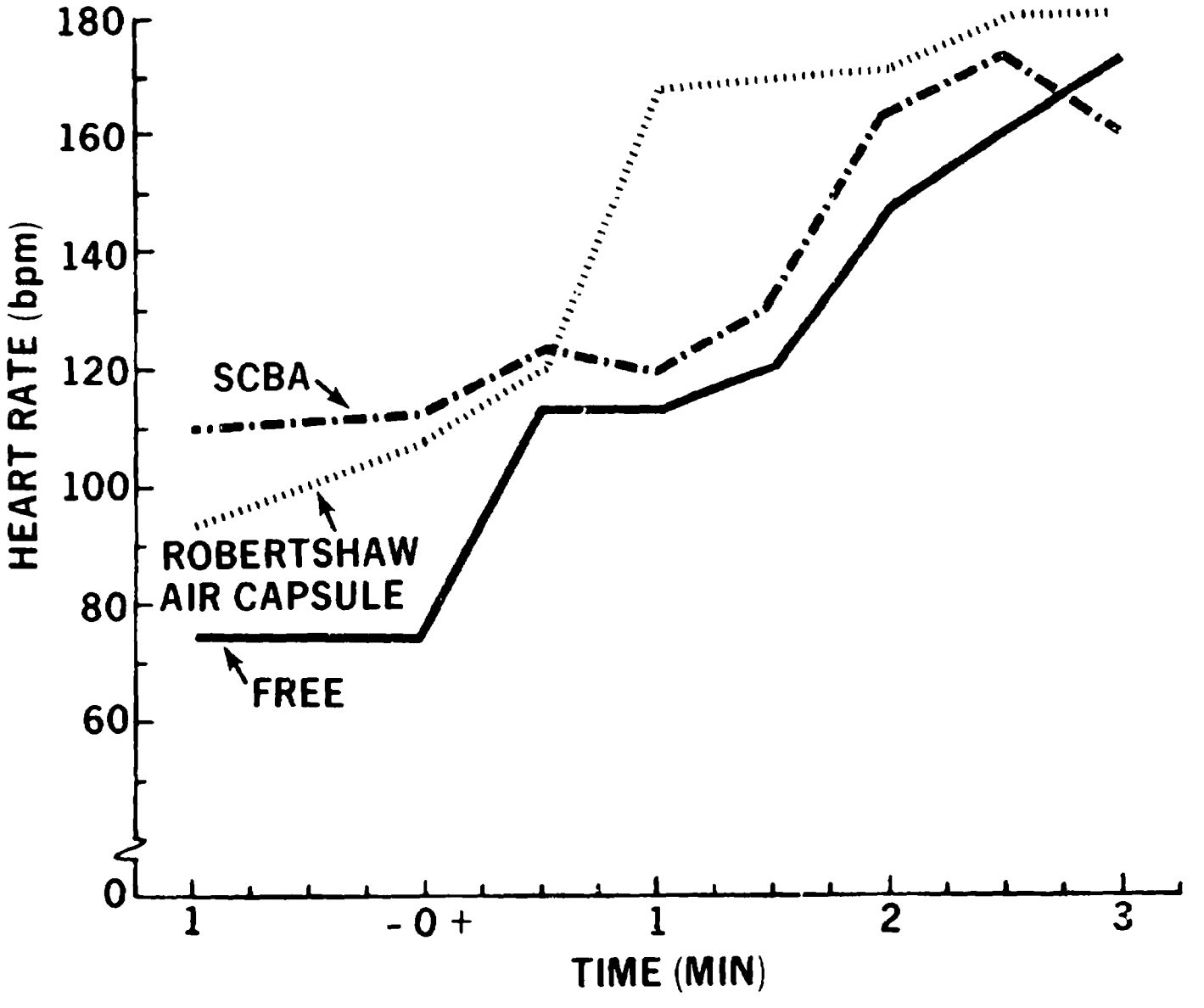

Figure 3. Heart rates observed for Subject 2 during a rapid evacuation of level 16 of SLC-4E with and without the use of respiratory protection equipment.

However, after the first minute of work the much lighter Robertshaw Air Capsule imposed an even greater cardiovascular stress as indicated by this subject's heart rate reaching 180 bpm, a level frequently associated with very strenuous work and impending exhaustion. This subject commented that, after descending only 3 flights, the bag collapsed around his head and face with every inspiration. At the same time, fogging of the inside of the capsule almost totally obstructed forward and downward vision which, along with total bag collapse, persisted throughout the remainder of the evacuation exercise. The onset of dizziness occasioned this subject to consider stopping at 3 different times during the tower descent, but he persisted and, accompanied by an observer, reached the safety tunnel where he experienced weakness, dizziness, and eventually syncope, all of which were relieved within seconds after removal of the air capsule. In light of the foregoing, subject 1 evacuated the SLC at a much slower pace when wearing the Robertshaw Air Capsule, and this is evidenced by his relatively lower heart rate (Table 9). However, in spite of this reduced evacuation pace, Subject 1 experienced a near total obstruction of vision by capsule fogging; only by glancing out the less fog-obstructed side of the capsule was this subject able to navigate the stairway descent. Although also noting slight episodes of dizziness and marked hyperventilation, this subject did not experience weakness or syncope upon reaching the tunnel at this reduced pace.

Subsequent exercises wearing the Robertshaw Air Capsule were conducted at a walking pace; corresponding evacuation times and heart rates are presented in Table 10.

The slower SLC evacuations represented by Table 10 were completed without complaint except for minor visual obstruction which was of concern during stairway descent.

TABLE 10. HEART RATE RESPONSES OBSERVED FOR TWO MEN WEARING A ROBERTSHAW AIR CAPSULE DURING WALKING EVACUATIONS OF SLC-4E AND SLC-4W

Subject No.	Total time (min:sec)		Heart rate (bpm) Time during evacuation (min)										
	Evacuation	Air supply	-1	0	½	1	1½	2	2½	3	3½	4	4½
			SLC-4E, Level 16										
1	4:24	4:49	80	55	90	80	85	91	85	75	98	83	86
2	4:13	4:48	85	92	113	113	116	128	128	143	120	115	116
			SLC-4W, Level 149										
1	4:02	4:47	68	66	90	87	93	90	98	94	97	79	
2	4:00	5:00	107	107	122	126	128	132	135	128	---	---	

DISCUSSION

Under the conditions of these experiments, i.e., an anticipated SLC evacuation unaccompanied by emotional stresses and/or by possible conditions obstructive to an emergency evacuation, a subject could rapidly descend from the highest work level (SLC-4E, Level 16) and arrive in the safety tunnel in about 3 min. However, such a rapid evacuation is neither safe nor is it recommended when wearing the Robertshaw Air Capsule; to proceed at such a pace with this breathing device would be dangerous due to (1) fogging that nearly completely obscures vision, (2) insufficient air supply that precipitates a feeling of suffocation, and (3) the risk of experiencing syncope, probably the result of hypoxia, which may preclude the wearer's ability to remove the capsule when the air supply has become exhausted.

On the other hand, a walking evacuation from level 16 of SLC-4E may be performed without incident while wearing the Robertshaw Air Capsule. This slower descent requires about 4 min 19 sec which allows little room for error when using this 5-min escape device.

It is obvious that the low level of air flow provided by the Robertshaw Air Capsule (approx. 25 liters/min) is adequate for a man performing work at a rate which would enable him to evacuate the SLC in 3 min. Myhre et al. (1) established the relationship between heart rate and ventilation for men exercising while wearing a SCBA. These data predict that the average heart rate of 159 bpm, observed in this study during rapid evacuation of SLC-4E while wearing a SCBA, would be accompanied by a ventilation rate averaging around 65 liters/min and an energy cost equivalent to about 73% of aerobic capacity (V_{O_2} max). Thus, the observed ventilation rate averaging 67 liters/min during these experiments is in good agreement with this prediction and supports the designation of this workload as being about 73% V_{O_2} max (1). Removing the burden of the 32.5 lb (14.7 kg) SCBA would allow these men to work at the same pace, but requiring only 60% of V_{O_2} max; this, in turn, would be accompanied by heart rates and ventilation rates approximating 138 bpm and 49 liters/min, respectively (1). Consequently, these latter values would be the best estimates of the workload experienced by these men during their rapid evacuation of level 16 on SLC-4E wearing the 4.65 lb (2.1 kg) Robertshaw Air Capsule; observed heart rates for these experiments averaged 146 during the third minute of work and were undoubtedly affected by varying degrees of hypoxia experienced by the subjects. Peak inspiratory flow rates during exercise requiring a ventilation of 49 liters/min would be about 180 liters/min (1).

In summary, to avoid the hypoxia experienced by the subjects during their rapid evacuation of SLC-4E, the escape device would have to provide fresh air at a rate of about 49 liters/min, and it must be capable of accommodating momentary peak requirements of 180 liters/min. Although some rebreathing of expired air may be inconsequential, such rebreathing during moderately hard work becomes excessive when wearing the Robertshaw Air Capsule which provides fresh air at only 25 liters/min. The result is an alleged progressive enrichment of breathing air with CO_2 which further stimulates respiration to greater

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1. Myhre, L. G., et al. Physiological limits of firefighters. EXL-TR-79-06, Tyndall Air Force Base, Florida 32403, June 1979.

ventilatory requirements. Although the use of the Robertshaw Air Capsule during a walking evacuation of a SLC was accomplished without major complaint, it is doubtful that such a restricted pace might be effectively imposed upon a worker during an emergency situation.

All of the above reservations related to the use of the Robertshaw Air Capsule are presented in the absence of information relative to the degree of protection from airborne contaminants offered by this device. Objective data relative to this protection factor await subsequent laboratory testing in which the breathing air inside the capsule is monitored while a subject, performing work simulating that of an SLC evacuation exercise, is exposed to a toxic simulant, e.g., NaCl. The heart rate and the ventilatory data collected in the present study will be used to establish a laboratory exercise scenario which will be representative of that required for Vandenberg AFB application.

APPENDIX A

DISTANCES TRAVERSED IN EVACUATING SPACE LAUNCH COMPLEX

	SLC-4E	SLC-4W
1. Distance from base of tower (pad) to top of stairway leading to ground level (paces):	24	29
2. Vertical distance from top of stairway to ground level (ft) (m):	18 (5.5)	19 (5.8)
3. Number of stairs (7½-in. (19.05-cm) rise) from pad to ground level:	29[a]	32[b]
4. Distance from last stair at ground level to tunnel stairway (paces):	74	64
5. Vertical distance from ground level to tunnel floor (ft) (m):	13 (4.0)	13 (4.0)
6. Number of stairs (8-in. (20.32-cm) rise) from ground level to tunnel floor:	19	19
7. Distance from bottom of SLC to (a) road intersection for 4E, and (b) fence with wire cutter for 4W (paces):	115	130 to stairway +34 6-in. (15 cm) steps +44 paces to fence

[a] Platform at step 14 (36-in. (91 cm) flat)

[b] Up 3 steps to reach platform; 2 paces on platform; down 32 steps to ground level